APPENDIX D. SMALL SCALE LABORATORY TESTS

D.1 INTRODUCTION

Computational fire models incorporate specific material properties in order to calculate fire development and growth for a given fire incident. These material properties, such as thermal conductivity, heat capacity, density, flame spread, and heat of combustion, are utilized by the model to predict if and when a component will ignite and how much energy or heat will be released as the component burns. The ignition and subsequent release of energy causes the fire to grow and spread throughout a structure.

The type and composition of the materials that were identified as being present inside the nightclub were characterized generically as polyurethane foam, ceiling tiles, wood paneling, carpet, and an industrial pyrotechnic device. This materials testing conducted by NIST and described in this appendix did not include any materials actually recovered from the nightclub.

The contribution of assorted fuels to fire spread and total heat release rate can be very different. For example, a polyurethane foam is low density and quick to ignite, but the mass of the foam is consumed in a relatively short period of time. The foam may contribute to quick initial fire growth, but typically would not have sufficient mass to carry the fire past the initial stages. Wood and carpet flooring have greater mass and are a larger source of energy than the foam, but the wood and carpet require longer times to ignite. Once ignited, both the wood and carpet could provide most of the energy released during a fire.

The contribution of a specific fuel is dependent on the relative amounts of the fuel and how quickly the fuel becomes involved in the fire. Wood is often found in flooring, wall paneling, and structural members such as studs, joists and rafters. Carpeting is typically used only as a floor covering. In a wood frame structure, the wood component of the fuel load may provide the bulk of the energy released. The location of the fuel can also impact when a how rapidly a specific fuel becomes a contributor to the heat release rate. For instance, wood paneling near the ceiling might become involved more quickly than wood flooring.

Five test series were conducted in this investigation: small scale heat release measurements using a cone calorimeter; ignition temperature determination by Southwest Research Institute; real-scale heat release and flame spread measurements of foam covered wall panels; heat flux and temperature measurements of pyrotechnic devices impinging on surfaces; and fire growth measurements in real-scale mockups of the raised platform (or stage), main floor, and alcove. This appendix describes the cone calorimeter and ignition temperature tests. The other test series are described in subsequent appendices: foam covered wall panels (Appendix E), pyrotechnic devices (Appendix F), and real-scale mockup (Appendix G).

D.2 CONE CALORIMETER TEST SERIES

Cone calorimeter experiments were conducted on five different materials at five different levels of external heat flux. The tests conducted on the polyether- and polyester-polyurethane foams and the external fluxes that were imposed on the samples are tabulated in Table D-1. Similar information for the wood, carpet, and ceiling tiles is located in Table D-2.

The data from the cone calorimeter is summarized in tables and is also plotted graphically for each of the 38 cone tests. The test protocol detailed in ASTM E 1354 [1] was used for these experiments. The E-

Table D-1. Cone Calorimeter Tests for Polyurethane Foams

Material	Thermal Flux kW/m²	Test ID	Manufacturer
Polyurethane Foam (Ester) Convoluted / Egg Crate Non-Fire Retardant Gray Color	35	PUF-NFR-A-1	A*
	35	PUF-NFR-A-2	
	35	PUF-NFR-A-3	
Polyurethane Foam (Ether) Convoluted / Egg Crate Non-Fire Retardant Gray Color	20	PUF-NFR-B-13	
	20	PUF-NFR-B-14	
	20	PUF-NFR-B-15	
	35	PUF-NFR-B-1	B*
	35	PUF-NFR-B-2	
	35	PUF-NFR-B-3	
	35	PUF-NFR-B-4	
	35	PUF-NFR-B-5	
	35	PUF-NFR-B-6	
	40	PUF-NFR-B-16	
	40	PUF-NFR-B-17	
	40	PUF-NFR-B-18	
	60	PUF-NFR-B-19	
	60	PUF-NFR-B-20	
	60	PUF-NFR-B-21	
	70	PUF-NFR-B-7	
	70	PUF-NFR-B-8	
	70	PUF-NFR-B-9	
	70	PUF-NFR-B-10	
	70	PUF-NFR-B-11	
Polyurethane Foam (Ether) Convoluted / Egg Crate Fire Retardant Gray Color	35	PUF-FR-1	C*
	35	PUF-FR-2	
	35	PUF-FR-3	

* Distributor purchases foam from a number of different sources based on price and availability. When foam arrives at warehouse, new stock is intermingled with old stock. Labeling on single pieces of foam identifies type of foam, such as polyurethane (ester), but does not provide information on manufacturer. Distributor unable to identify specific manufacturer of purchased foam. Fire retardant foam was purchased in single lot. Non-fire retardant foam purchased in two lots. Cannot rule out possibility that individual foam within the same purchase came from different sources.

1354 test method utilizes a cone calorimeter (Figure D-1) to collect data on heat release rate, mass loss rate, optical density of smoke, and gas concentrations in combustion products. The cone calorimeter exposes relatively small samples (10 cm x 10 cm) to a uniform thermal flux. These samples were stored

Table D-2. Cone Calorimeter Tests for Wood, Carpet, and Ceiling Tile.

Material	Thermal Flux kW/m^2	Test ID
Wood Paneling 5 mm thick Plywood Substrate	35	WP-01
	35	WP-02
	35	WP-03
	70	WP-04
	70	WP-05
	70	WP-06
Carpet Flooring 100% Filament Olefin Ave. Tufted Face Weight 39 oz. Polyester short nap 0.25” thick Beige color	35	CF-01
	35	CF-02
	35	CF-03
	70	CF-04
	70	CF-05
	70	CF-06
Ceiling Tile – 942 B Textured 610 mm x 1219 mm x 16 mm (24 in x 48 in x 0.6250 in)	35	CT-01
	35	CT-02
	35	CT-03
	70	CT-04
	70	CT-05
	70	CT-06

in a controlled humidity (50 % relative humidity) and temperature (23 ^oC) room for at least two weeks prior to testing. Each sample was wrapped in an aluminum foil, except for the exposed side, and positioned in a stainless steel specimen holder (Figure D-2). The thermal flux which is generated via a cone shaped electrical resistance heater was set to the desired test value of 20 kW/m^2, 35 kW/m^2 , 40 kW/m^2, 60 kW/m^2, or 70 kW/m^2, and verified using a heat flux meter. The sample in the specimen holder was then positioned horizontally on the load cell and exposed to the thermal flux. An electric spark was used to ignite the combustible gases near the surface of the sample. A sample of polyurethane foam that was ignited under the cone is shown in Figure D-3. The smoke and combustion products were drawn through the center of the cone heater and into the instrumented exhaust duct. The load cell tracked mass loss rate throughout each burn. The small amount of residue left in the aluminum tray afterthe cone tests of three polyurethane foam samples is shown in Figure D-4. Additional instruments allowed the optical density of the smoke and gas concentrations to be monitored continuously. The distance between the top surface of the sample and the cone housing was 25 mm. The energy release per mass of oxygen depleted was assumed to be a constant 13.1 MJ/kg. While the cone calorimeter can provide heat release rate as a function of thermal flux, the impact of ventilation, corner geometries, and composite assemblies are difficult to characterize.

A test plus two replicates of each sample (total of three tests) were conducted with the cone calorimeter providing an external heat flux of 20 kW/m^2, 35 kW/m^2, 40 kW/m^2, 60 kW/m^2, or 70 kW/m^2. The lower thermal fluxes represent a radiation exposure the materials might experience early in the fire

Figure D-1. Cone Calorimeter – Test Chamber (right side), computer display (center), and gas analyzers (left side).

Figure D-2. Sample of Polyurethane Foam Placed in Aluminum Foil Tray on Top of Horizontal Sample Holder.

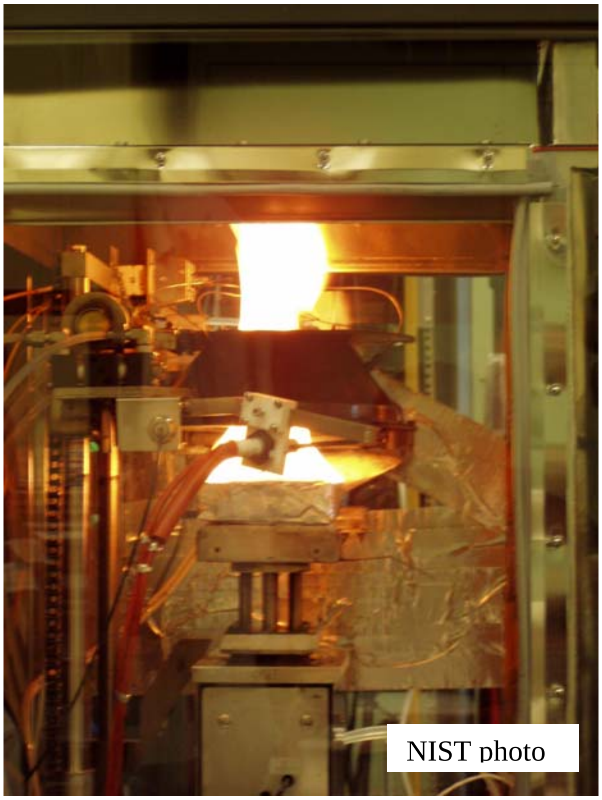

Figure D-3. Test Specimen – Exposed to thermal flux from cone shaped heater, combustion products drawn through center of cone, sample positioned on load cell.

Figure D-4. Burn Residue of Polyurethane Foam after Cone Calorimeter Test.

development. The higher thermal fluxes simulate conditions that the material might encounter near the peak heat release rate in the fire.

The data that were collected during the cone calorimeter tests are summarized in tables in Section D.2.8 of this appendix. The data tables provide the time to sustained ignition, peak heat release rate, time to peak heat release rate, total heat release, 60 s average heat release rate, total mass loss, average mass loss rate, average effective heat of combustion, average smoke yield, average carbon dioxide yield, average carbon monoxide yield, time to ignition, time to flameout, and a number of specimen properties.

D.2.1 Polyurethane Plastics and Flammability Ratings

Polyurethane refers to a large category of materials including surface coatings, elastomers, and foams, rigid or flexible, and thermoplastic or thermosetting. While large quantities of polyurethanes are used to manufacture adhesives and protective coatings, the foam type of polyurethane is widely used in the production of upholstered furniture, bedding, sponges, toys, wearing apparel, and medical dressings. Rigid urethane foams are used for insulation in building constructions. Flexible polyurethane foams are used in packaging materials and acoustical insulation panels. The urethane linkage, which all polyurethanes have in common, involves the reaction of an isocyanate group with a hydroxyl-containing group. A more detailed description of urethane formation chemistry is in Appendix H.

Fire retardant additives or compounds can be incorporated into polyurethane foam during the manufacturing procedure or can be applied to the foam in a post-production process. The molecular structure of polyurethane foam can also be adjusted to provide improved fire resistant properties. The polyurethane foam material itself is still a hydrocarbon compound, a long chain carbon based material that can act as a fuel source.

Fire performance tests, such as Flammability of Plastic Materials for Parts in Devices and Appliances (Underwriters Laboratories UL 94) have been developed to measure flammability characteristics of plastic materials. However, UL 94 specifically is <u>not</u> intended for foam plastics used in building construction or finish materials. Three of the UL 94 flame classifications relate to low density foam materials: HF-1, HF-2, and HBF. In each test, a small sample is positioned horizontally and exposed to a flame for 60 seconds. After the 60 second flame exposure, the flame is removed and the time required for the flaming to cease (after-flame) and the flaming and glowing to cease (after-glow) are monitored. The distance the flame travels across the sample is also recorded. Foams rated as HBF can sustain a limited flame spread; foams rated as HF-2 must self-extinguish in less than 30 s, but their drips are sufficient to ignite cotton fabric; an HF-1 rating is similar to HF-2, except that any dripping materials do not ignite a cotton fabric placed underneath the foam sample. The fire retardant foam from supplier C was identified by the supplier as being rated HF-1; the polyurethane foams from Lots A and B were not rated, and are thus considered non-fire retardant.

Fire retardant polyurethane foams may not ignite as quickly as non-fire retardant foams, and they also may have lower peak heat release rates than non-fire retardant foams. The classification of a foam as "fire retardant," however, does not prevent it from igniting and contributing to the fuel load and fire spread once the material is exposed to the high temperatures and high thermal flux conditions of a room fire. Both fire retardant foam and non-fire retardant foam were included in the cone calorimeter tests to help characterize time to ignition and heat release rate for each.

D.2.2 Test Results -- Non-fire Retardant Polyurethane Foam

Both polyether and polyester formulations of polyurethane can be used as packaging materials. The polyurethane foam which is offered for packaging typically does not include any fire retardant additives or incorporate any fire retardant compounds into the urethane structure. As a packaging material, the polyurethane foam (ether and ester) is commercially available in a range of sizes including 1.22 m (4 ft) x 2.44 m (8 ft) sheets. The gray colored foam can be obtained in several geometries including solid blocks, uniform thickness sheets, and convoluted or “egg-crate” sheets. In The Station nightclub, polyurethane foam had been installed on the rear wall, raised platform (stage) wall, and in the alcove as a sound attenuation material (see Figure 4-1). Photographs of the nightclub interior do not clearly demonstrate whether staples, nails, organic adhesive or some combination of all three were used to mount the foam on the wall. The polyurethane foam appeared to have been mounted over the top of the previous wall material, which, depending on the location may have been either wood paneling, gypsum board, or rigid polystyrene foam between vertical wood studs. The foam was installed in either full 1.22 m x 2.44 m sheets or was trimmed to fit the raised platform (stage), alcove, or rear wall geometry.

Each 1.22 m x 2.44 m sheet was supplied in a compressed roll, approximately 0.30 m (12 in) in diameter and 0.41 m (16 in) wide. After removing the wrapping, each compressed roll expanded to a 1.22 m x 2.44 m sheet. While the rear surface of each sheet was flat, the front side was convoluted. These convolutions were a series of peaks and depressions that resembled the surface of a continuous egg crate. There were approximately 36 peaks and 36 depressions per 0.09 m^2 (1 ft^2). Peak to peak spacing was approximate 0.05 m (2 in) for all the foam (Figure D-5 and D-6). The thickest dimension of the foam was measured from the tip of a peak to the back surface. The thinnest dimension of the foam was measured from the bottom of a depression to the back surface. There were noticeable differences in thickest and thinnest dimensions between the foam purchased from supplier A and supplier B. Foam from supplier A was measured at 0.04 m (1.5 in) and 0.009 m (0.35 in) at its thickest and thinnest dimensions, respectively (Figure D-5). Foam obtained from supplier B was measured at 0.03 m (1.2 in) and 0.015 m (0.6 in) at its thickest and thinnest dimensions, respectively (Figure D-6).

Twenty-three test samples were exposed to thermal fluxes ranging from 20 kW/m^2 to 70 kW/m^2. The heat release rate for each sample is plotted versus time in Figures D-7 through D-13.

The non-fire retardant polyurethane foam samples exposed to an external heat flux of 20 kW/m^2 reached peak heat release rates from 440 kW/m^2 to 460 kW/m^2 in approximately 50 seconds. The average time to sustained ignition was 14 seconds (Table D-3). When exposed to 35 kW/m^2 of external heat flux, the non-fire retardant polyurethane foam reached its peak heat release rate in approximately 30 seconds. Peak heat release rates for all nine foam samples ranged from 520 kW/m^2 to 680 kW/m^2 with an average of about 590 kW/m^2. There did not appear to be a significant difference in the range of peak heat release rates between the two suppliers. The average time to sustained ignition was 6 seconds and average time to peak heat release rate was 30 seconds.

Samples of the non-fire retardant foam, PUF-NFR-B, were exposed to external heat fluxes of 40 kW/m^2 and 60 kW/m^2, reaching peak heat release rates in approximately 29 seconds and 24 seconds, respectively. Peak heat release rates for the three 40 kW/m^2 foam samples ranged from 700 kW/m^2 to 880 kW/m^2 with an average of about 820 kW/m^2. The three 60 kW/m^2 exposures produced peak heat release rates ranging from 1000 kW/m^2 to 1300 kW/m^2 with an average of about 1150 kW/m^2. The average time to sustained ignition was 4 seconds and 3 seconds for the 40 kW/m^2 and 60 kW/m^2 exposures, respectively.

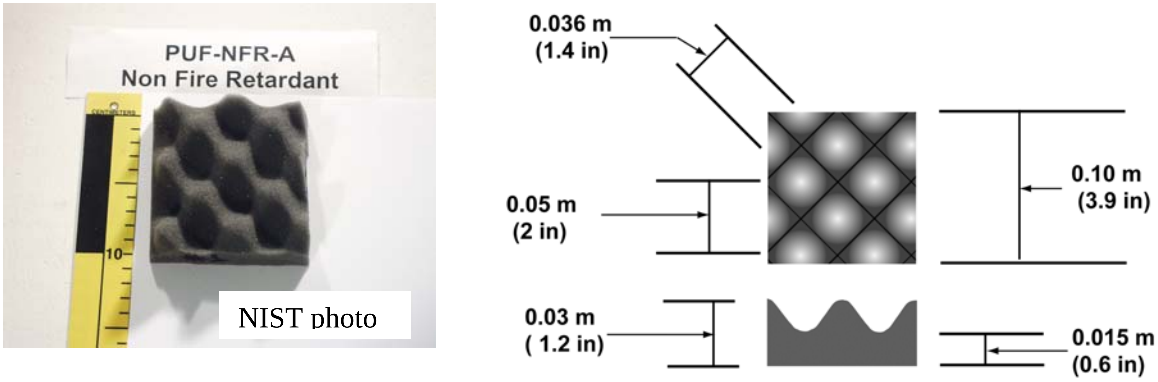

Figure D-5. Photograph and Dimensioned Diagram of Non Fire Retardant Foam Lot A (PUF-NFR-A).

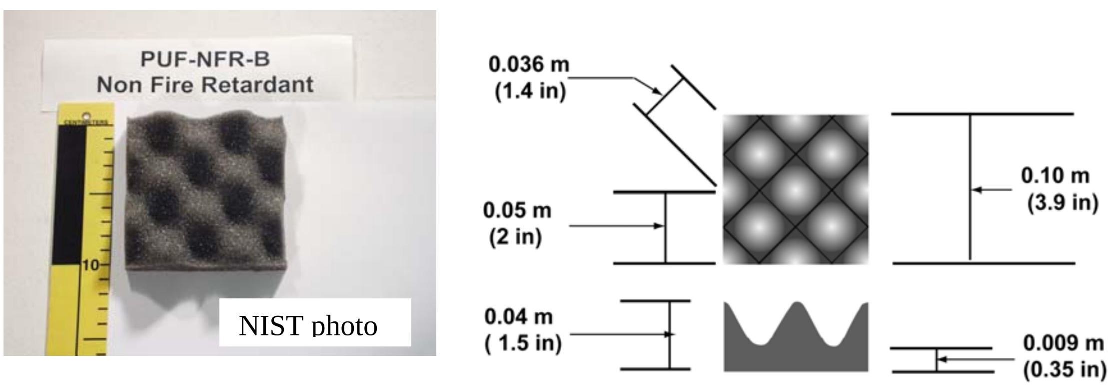

Figure D-6. Photograph and Dimensioned Diagram of Non Fire Retardant Foam Lot B (PUF-NFR-B).

When exposed to70 kW/m^2 of external heat flux, the non-fire retardant polyurethane foam reached its peak heat release rate in approximately 20 seconds. Peak heat release rates for all five foam samples ranged from 810 kW/m^2 to 1094 kW/m^2 with an average of 970 kW/m$^{2.}$ At the higher flux it required an average 3 seconds to reach sustained ignition and an average of 21 seconds to reach the peak heat release rate.

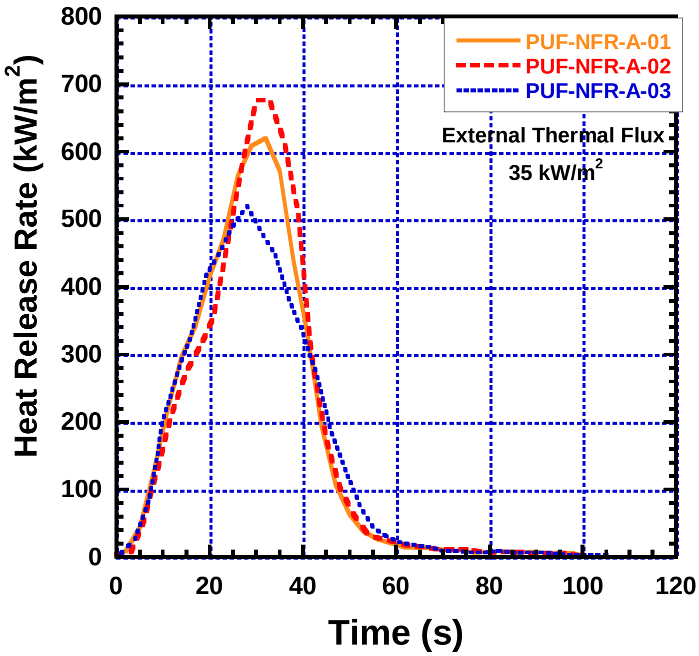

Figure D-7. Heat Release Rate versus Time for Polyurethane Foam Exposed to 35 kW/m^2 of External Heat Flux. Samples PUF-NFR-A-01, PUF-NFR-A-02, and PUF-NFR-A-03.

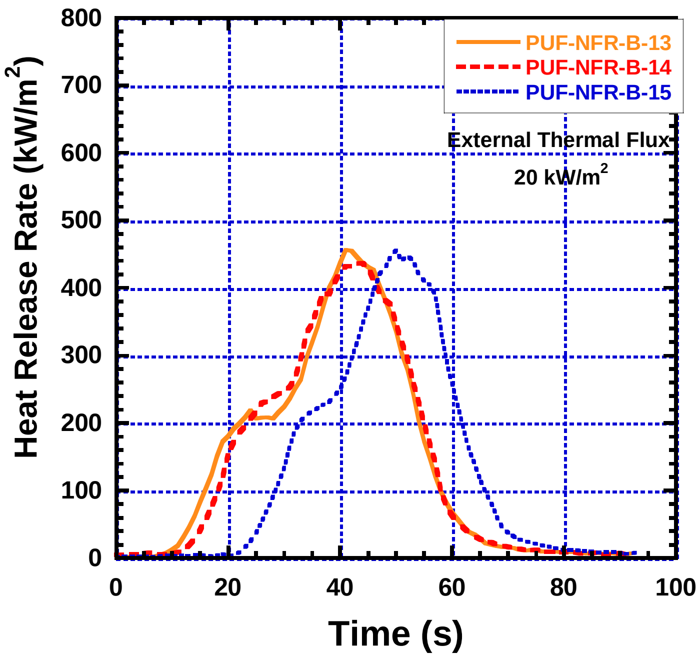

Figure D-8. Heat Release Rate versus Time for Polyurethane Foam Exposed to 20 kW/m^2 of External Heat Flux (PUF-NFR-B). Samples PUF-NFR-B-13, PUF-NFR-B-14, and PUF-NFR-B-15.

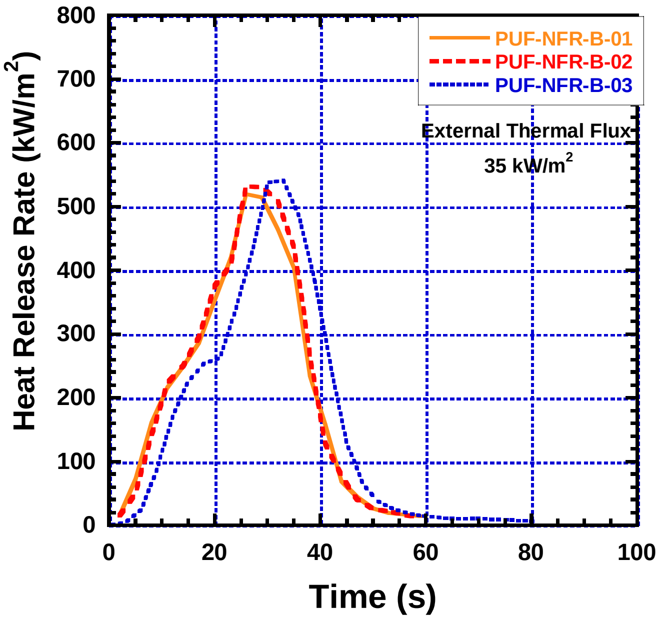

Figure D-9. Heat Release Rate versus Time for Polyurethane Foam Exposed to 35 kW/m^2 of External Heat Flux (PUF-NFR-B). Samples PUF-NFR-B-01, PUF-NFR-B-02, and PUF-NFR-B-03.

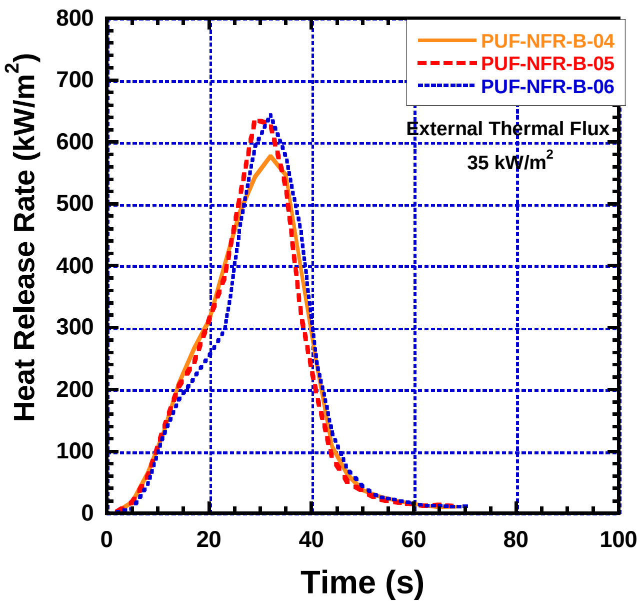

Figure D-10. Heat Release Rate versus Time for Polyurethane Foam Exposed to 35 kW/m^2 of External Heat Flux (PUF-NFR-B). Samples PUF-NFR-B-04, PUF-NFR-B-05, and PUF-NFR-B-06.

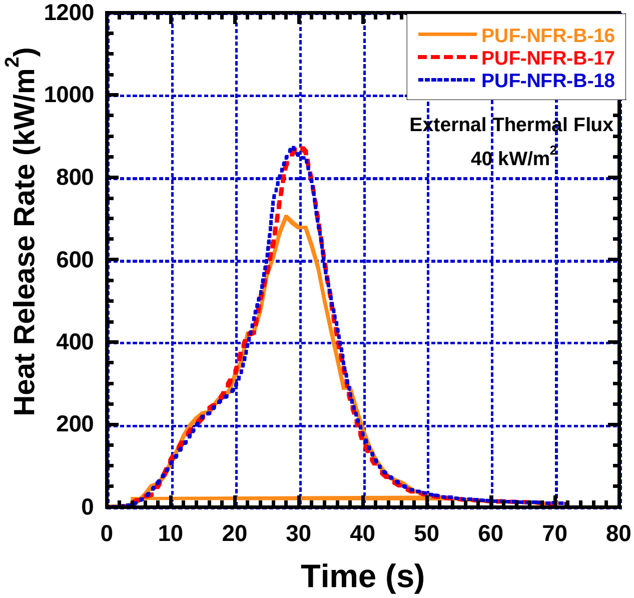

Figure D-11. Heat Release Rate versus Time for Polyurethane Foam Exposed to 40 kW/m^2 of External Heat Flux (PUF-NFR-B). Samples PUF-NFR-B-16, PUF-NFR-B-17, and PUF-NFR-B-18.

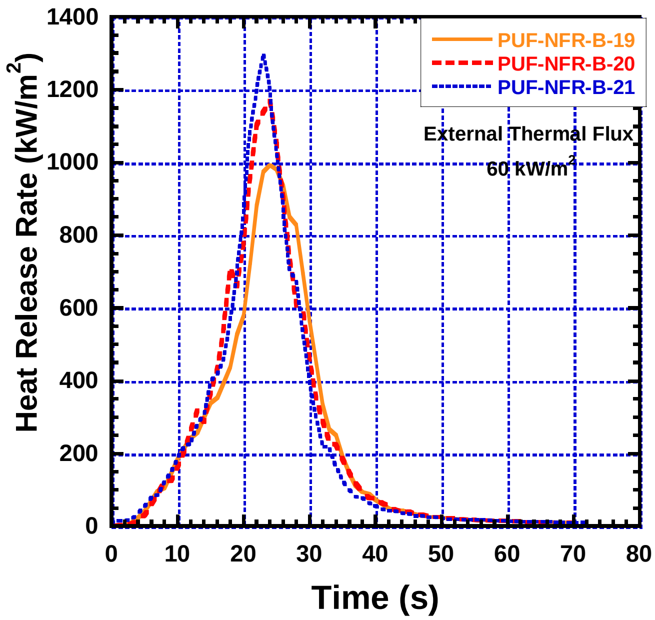

Figure D-12. Heat Release Rate versus Time for Polyurethane Foam Exposed to 60 kW/m^2 of External Heat Flux (PUF-NFR-B). Samples PUF-NFR-B-19, PUF-NFR-B-20, and PUF-NFR-B-21.

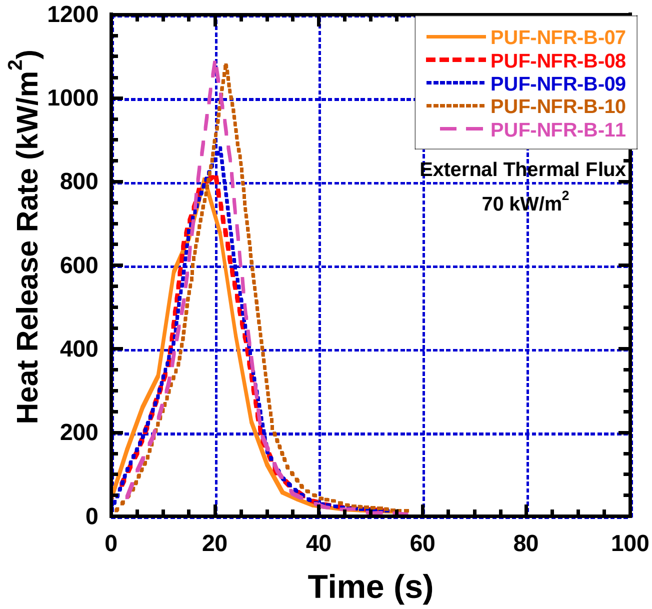

Figure D-13. Heat Release Rate versus Time for Polyurethane Foam Exposed to 70 kW/m^2 of External Heat Flux (PUF-NFR-B). Samples PUF-NFR-B-07, PUF-NFR-B-08, PUF-NFR-B-09, PUF-NFR-B-10, and PUF-NFR-B-11.

D.2.3 Test Results -- Fire Retardant Polyurethane Foam

Polyether polyurethane foam which is intended for packaging applications typically does not have additional fire retardant qualities, either through additives included in the manufacturing process or post-production treatments. It is still useful to characterize the performance of fire retardant foam in order to understand how the fire growth and spread differ from the non-fire retardant foam.

NIST purchased a number of 1.22 m (4 ft) x 2.44 m (8 ft) sheets of fire retardant polyester polyurethane foam from a commercial supplier. Unfortunately, the distributor was not able to identify the manufacturer of the foam.

As with the non-fire retardant foam, the fire retardant foam was supplied in compressed rolls, which were allowed to expand to a 1.22 m x 2.44 m sheet. Both the non-fire retardant and fire retardant foams were similar in the size, distribution, and number of peaks and depressions. There were approximately 36 peaks and 36 depressions per 0.09 m^2 (1 ft ^{2}). The thickest dimension of the foam was measured from the tip of a peak to the back surface. The thinnest dimension of the foam was measured from the bottom of a depression to the back surface. The fire retardant foam more closely resembled the non fire retardant foam obtained in the first lot (B). Fire retardant foam was measured at 0.03 m (1.5 in) and 0.010 m (0.4 in) at its thickest and thinnest dimensions, respectively (Figure D-14).

The heat release rate for each sample is plotted versus time in Figure D-15. When exposed to 35 kW/m^2 of external heat flux, the fire retardant polyurethane foam reached its peak heat release rate in approximately 36 seconds. Peak heat release rates for all three foam samples ranged from 430 kW/m^2 to 480 kW/m^2 with an average of 453 kW/m^2. Each of the three fire retardant samples exhibited lower peak heat release rates than for the non-fire retardant foam samples. It required about twice as long for the fire retardant foam, 13 seconds, to reach sustained ignition as required by the non-fire retardant foam (Table D-3). The time to peak heat release was longer for the fire retardant foam, increasing by about 20 %.

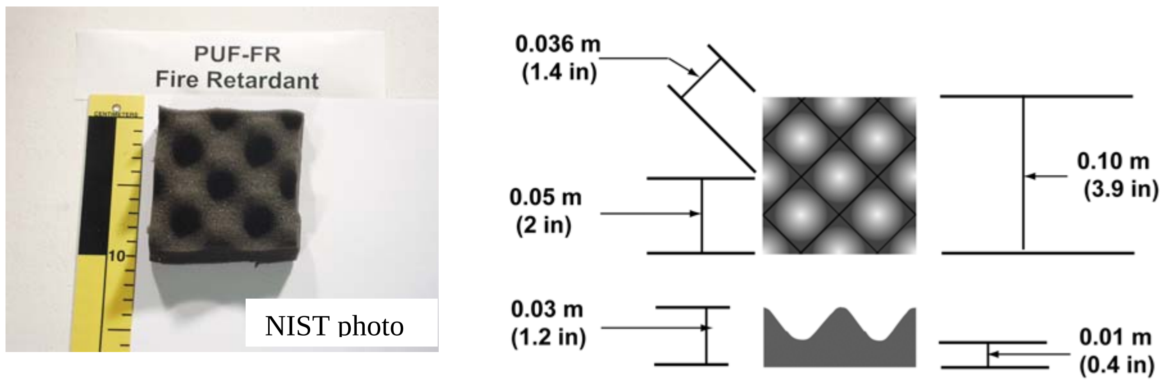

Figure D-14. Photograph and Dimensioned Diagram of Fire Retardant Foam (PUF-FR).

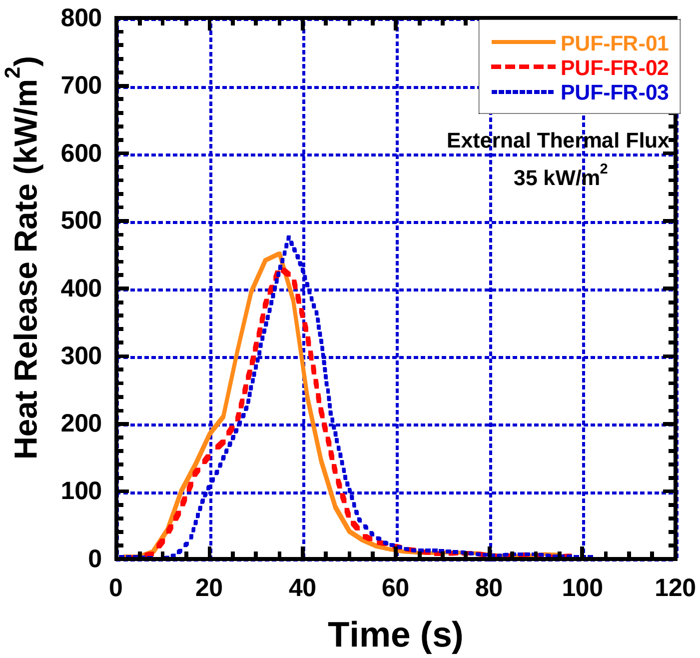

Figure D-15. Heat Release Rate versus Time for Fire Retarded Polyurethane Foam Exposed to 35 kW/m^2 of External Heat Flux. Samples PUF-FR-01, PUF-FR-02, and PUF-FR-03.

Table D-3 Time to Sustained Ignition, Time to Peak HRR, and Peak HRR for Polyurethane Foam Tested at National Institute of Standards and Technology.				
ID	**External Thermal Flux kW/m^2**	**Time to Sustained Ignition, Seconds**	**Time to Peak Heat Release, Seconds**	**Peak Heat Release Rate kW/m^2**
PUF-FR-1	35	11	35	452
PUF-FR-2	35	11	35	432
PUF-FR-3	35	16	37	476
	Average	**13**	**36**	**453**
PUF-NFR-A-1	35	9	32	620
PUF-NFR-A-2	35	7	30	676
PUF-NFR-A-3	35	6	28	520
	Average	**7**	**30**	**605**
PUF-NFR-B-13	20	8	41	457
PUF-NFR-B-14	20	12	44	437
PUF-NFR-B-15	20	22	50	456
	Average	**14**	**45**	**450**
PUF-NFR-B-1	35	4	26	519
PUF-NFR-B-2	35	5	26	532
PUF-NFR-B-3	35	9	33	541
PUF-NFR-B-4	35	5	32	577
PUF-NFR-B-5	35	5	29	637
PUF-NFR-B-6	35	5	32	644
	Average	**6**	**30**	**586**
PUF-NFR-B-16	40	4	28	706
PUF-NFR-B-17	40	3	30	878
PUF-NFR-B-18	40	4	29	877
	Average	**4**	**29**	**820**
PUF-NFR-B-19	60	4	24	993
PUF-NFR-B-20	60	3	24	1170
PUF-NFR-B-21	60	3	23	1299
	Average	**3**	**24**	**1154**
PUF-NFR-B-7	70	4	18	806
PUF-NFR-B-8	70	3	20	820
PUF-NFR-B-9	70	3	21	881
PUF-NFR-B-10	70	3	22	1083
PUF-NFR-B-11	70	3	20	1094
	Average	**3**	**21**	**970**

D.2.4 ATF Test Results -- Polyether Polyurethane Foam from the Nightclub

A roll of gray convoluted foam was recovered from the basement of the burnt out nightclub one day after the fire and turned over to the West Warwick Police Department as evidence. The foam did not appear to have been painted or to have been mounted on any surface. Samples from this recovered foam were tested by the Bureau of Alcohol, Tobacco, and Firearms (ATF) in a cone calorimeter at the ATF Fire Laboratory in Maryland.

The time to sustained ignition, time to peak heat release rate, and the peak heat release rate for thermal flux exposures of 20 kW/m^2, 40 kW/m^2, and 60 kW/m^2 reported by ATF [2] are shown in Table D-4. For the 20 kW/m^2 flux exposure the ATF polyether foam required 9 seconds for sustained ignition which is less than the 22 seconds the NIST polyether foam required at 20 kW/m^2. The time to peak heat release rate was also longer for the NIST foam, 50 seconds, than for the ATF foam, 37 seconds. For the ATF foam, the average peak heat release rate at 20 kW/m^2, 260 kW/m^2, was about half of the peak release rate for the NIST foam.

The 40 kW/m^2 heat flux exposure for the ATF foam resulted in a peak heat release rate of 297 kW/m^2, less than half that observed for the NIST polyether foam. The time to peak heat release rate was 31 seconds and 29 seconds for the ATF and NIST foams, respectively. The time to sustained ignition was 3 seconds for the ATF tests and 4 seconds for the NIST samples. For the highest rate of external thermal flux tested by ATF, 60 kW/m^2, the peak heat release rate, 415 kW/m^2, was about a third of the value of 1154 kW/m^2 that was reported during the NIST cone calorimeter testing at 60 kW/m^2. The time to sustained ignition was 1 second for the ATF polyether samples as compared to 3 seconds for the NIST tests, and the time to peak heat release was 26 seconds and 23 seconds for the ATF and NIST samples, respectively.

Table D-4 Time to Sustained Ignition, Time to Peak HRR, and Peak HRR for Polyurethane Foam Tested at ATF [13].

Sample ID	External Thermal Flux kW/m^2	Time to Sustained Ignition, Seconds	Time to Peak Heat Release Rate, Seconds	Peak Heat Release Rate kW/m^2
03F0011-01	20	9	35	257
03F0011-02	20	8	39	267
03F0011-03	20	11	37	257
	Average	**9**	**37**	**260**
03F0011-04	40	2	29	301
03F0011-05	40	3	31	291
03F0011-06	40	3	32	298
	Average	**3**	**31**	**297**
03F0011-07	60	1	25	453
03F0011-08	60	2	29	415
03F0011-09	60	1	25	377
	Average	**1**	**26**	**415**

D.2.5 Test Results -- Acoustical Ceiling Tiles

A suspended or dropped ceiling had been installed in the nightclub except for in the sunroom, the raised platform (stage) area, and the dance floor areas (refer to Fig. 4-3). Each 0.61 m (2 ft) x 1.22 m (4 ft) x .016 m (0.625 in) panel had been installed or dropped into a metal grid support system. Photographs of the nightclub interior clearly demonstrate that the ceiling tiles had been painted black. It was not clear from the photographs whether the paint had been applied by brush, roller, or spray can. The surface of the tiles had a glittery appearance that may have been a result of the wet paint being dusted with glitter or sparkle dust. Some of the glitter would have become partially embedded in the wet paint and would have

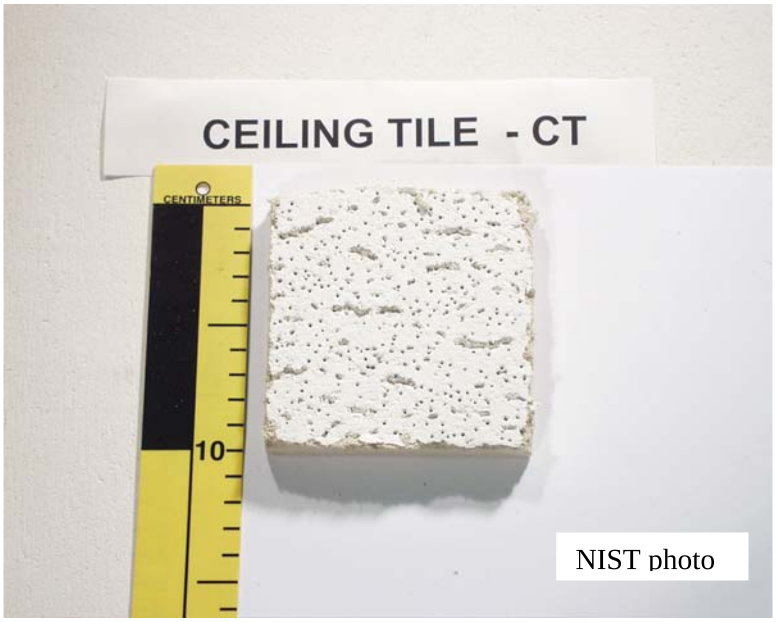

Figure D-16. Photograph of Acoustical Tile Showing Factory Painted Surface.

provided a more glittery or sparkling appearance that was observed in some of the video of the nightclub interior.

Labeling found on a surviving acoustical tile indicated that that the surviving tile was a mineral fiber type of material, a 942 (residential coding) or 755 (commercial coding). Samples of 942B acoustical tiles were purchased from a local supplier for these cone calorimeter tests. The front side of each panel (Figure D-16) exhibited a factory-applied coat of white vinyl-latex paint while the rear side of each panel was unpainted. Samples that measured 0.1 m x 0.1 m were cut from the larger panels. These samples were then stored in a controlled humidity (50 % relative humidity) and temperature (23 ^{o}C) room for at least two weeks. Each sample was wrapped in an aluminum foil, except for the exposed side, and positioned in the cone calorimeter. In all tests, the painted side was exposed to the thermal flux.

Three test samples were exposed to thermal flux at 35 kW/m^2. Each test was terminated after 3 min of exposure when none of the three samples ignited (Table D-5). An additional three test samples were exposed to thermal flux at 70 kW/m^2. The heat release rate for each sample is plotted versus time in Figure D-17. The heat release curves show an initial peak, a period of decline, and then a second peak.

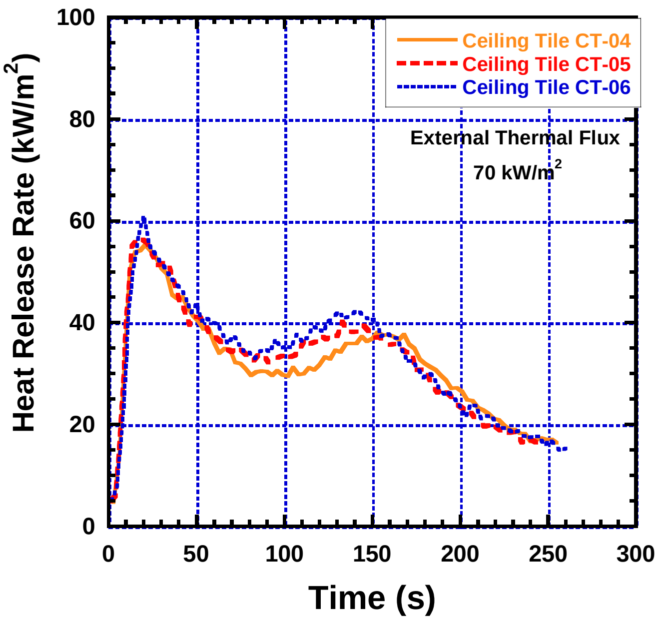

Figure D-17. Heat Release Rate versus Time for Ceiling Tile Exposed to 70 kW/m^2 of External Heat Flux (PUF-CT). Samples are CT-04, CT-05, and CT06.

The second peak was observed because as the material initially burns, some of the energy released by the combustion process is lost or conducted away into the unburned portion of the sample. As the test continued, the temperature of the unburned sample gradually increased with the continual heating from either the external flux or the combustion of the fuel itself. Eventually, the temperature of the material increased to the point where much less energy is lost through conduction. At this point, the energy, which was previously being conducted away, became available to increase the pyrolysis and subsequent burning of the fuel. This increase in the pyrolysis and burning resulted in a second peak in the heat release rate. Sometimes, if a sample contained some components that would ignite at a substantially lower temperature, these components would burn first and other components that had a higher ignition temperature would remain. As the sample temperature continued to increase and eventually reached the ignition temperature of the remaining components, even the higher ignition temperature fuel would begin to burn. This additional burning would have caused an increase in the heat release rate at some time after the initial peak due to the burning of the low temperature components.

When exposed to 35 kW/m^2 of external heat flux, the ceiling tiles did not ignite. As the thermal flux was increased to70 kW/m^2, ignition did occur and the samples reached their peak heat release rate in approximately 20 seconds. Peak heat release rates for all three ceiling tile samples ranged from 55 kW/m^2 to 61 kW/m^2 with an average of 57 kW/m^2.

D.2.6 Wood Paneling

Wood paneling had been installed in the nightclub around the raised platform area, around the sunroom, back bar area, and entry way (Figure 4-4). It is not clear whether or not there were any areas where polyurethane foam had been installed over wood paneling. Interior photographs of the nightclub did not provide sufficient information to identify the specific brand or type of paneling.

A veneer type paneling, which utilizes a plywood substrate, was selected as being most representative of the fuel load contributed by the paneling. The wood paneling was purchased from a local retailer in 1.22m (4 ft) x 2.44 m (8 ft) sheets. The 0.0005 m (0.0125 in) birch veneer was laminated to a 0.005 m (0.25 in) thick three-ply Luan mahogany backer layer. The front side of each panel (Figure D-18) had a glossy coat of finish while the rear side of each panel was unfinished plywood. Samples that measured 0.1 m x 0.1 m were cut from the larger panels. These samples were then stored in a controlled humidity (50 % relative humidity) and temperature (23 ^{o}C) room for at least two weeks. Then, each sample was wrapped in an aluminum foil, except for the exposed side, and positioned in the cone calorimeter. In all tests, veneer side was exposed to the thermal flux.

When exposed to 35 kW/m^2 of external heat flux, the wood paneling reached its average peak heat release rate, 440 kW/m^2 in approximately 130 s (Figure D-19). Peak heat release rates for all three wood samples ranged from 413 kW/m^2 to 460 kW/m^2. At the lower thermal flux, each sample required about 40 seconds to achieve sustained ignition. At the higher flux rate of 70 kW/m^2, the wood panel samples required much less time, on average 15 seconds, to sustain ignition (Figure D-20). The higher external flux resulted in a higher average peak heat release rate of 530 kW/m^2, but required substantially less time, 85 seconds, to achieve the peak value.

The heat release curves exhibited a two-peak shape, with the second peak much greater than the first peak. Each wood panel sample charred significantly as it burned and the char represented a greater fraction of the total available fuel than that which was burned early in the test. In the higher thermal flux exposure, the additional flux caused more of the fuel to be burned early in the test, so the two peaks were closer in value.

Figure D-18. Photograph of Wood Panel Sample Showing Veneer Surface.

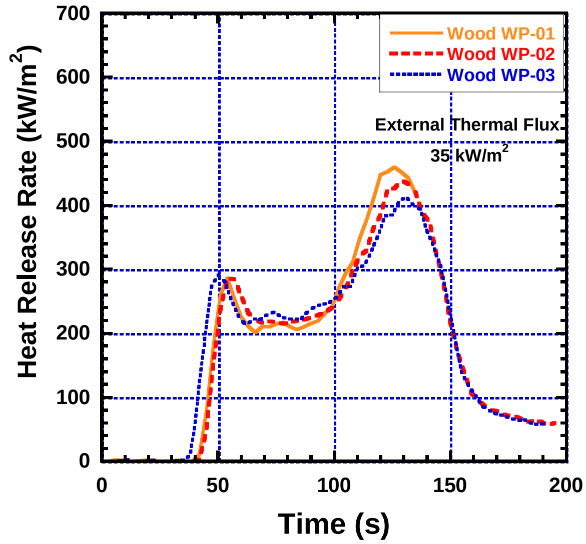

Figure D-19. Heat Release Rate versus Time for Wood Paneling Exposed to 35 kW/m^2 of External Heat Flux (WP). Samples are WP-01, WP-02, and WP-03.

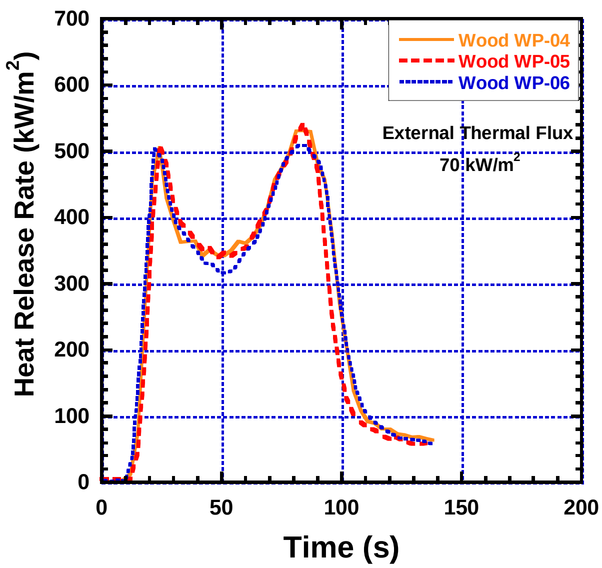

Figure D-20. Heat Release Rate versus Time for Wood Paneling Exposed to 70 kW/m^2 of External Heat Flux (WP). Samples are WP-04, WP-05, and WP-06.

Table D-5 Cone Calorimeter Results for Ceiling Tile, Wood Panels, & Carpet

Sample ID	External Thermal Flux, kW/m^2	Time to Sustained Ignition, seconds	Time to Peak Heat Release Rate, seconds	Peak Heat Release Rate kW/m^2
CT-01	30	Did not ignite		
CT-02	30	Did not ignite		
CT-03	30	Did not ignite		
CT-04	70	9	21	55
CT-05	70	7	19	56
CT-06	70	8	20	61
	Average	**8**	**20**	**57**
WP-01	35	43	126	460
WP-02	35	43	129	439
WP-03	35	37	131	413
	Average	**41**	**129**	**437**
WP-04	70	14	84	531
WP-05	70	16	84	543
WP-06	70	14	85	509
	Average	**15**	**85**	**526**
CF-01	35	38	221	474
CF-02	35	68	178	718
CF-03	35	40	206	536
	Average	**54**	**192**	**627**
CF-04	70	20	79	1378
CF-05	70	19	79	1289
CF-06	70	20	76	1447
	Average	**20**	**78**	**1371**

D.2.7 Test Results -- Carpet Flooring

Carpet flooring had been installed in the nightclub on the elevated section along the rear wall and around the raised platform area. (Figure 4-5). Interior photographs of the nightclub did not provide sufficient information to identify the specific brand or type of carpeting.

A closed-loop olefin carpet with a binding layer was selected as representing the fuel load contributed by the carpeting. The carpet was purchased from a local supplier in a 3.2 m (12 ft) wide x 15.7 m (50 ft) long continuous roll. The 0.006 m (0.25 in) nylon pile was embedded in a 0.002 m (0.1 in) thick binding layer. Samples that measured 0.1 m x 0.1 m were cut from the roll (Figure D-21). These samples were then stored in a controlled humidity (50 % relative humidity) and temperature (23 ^{o}C) room for at least

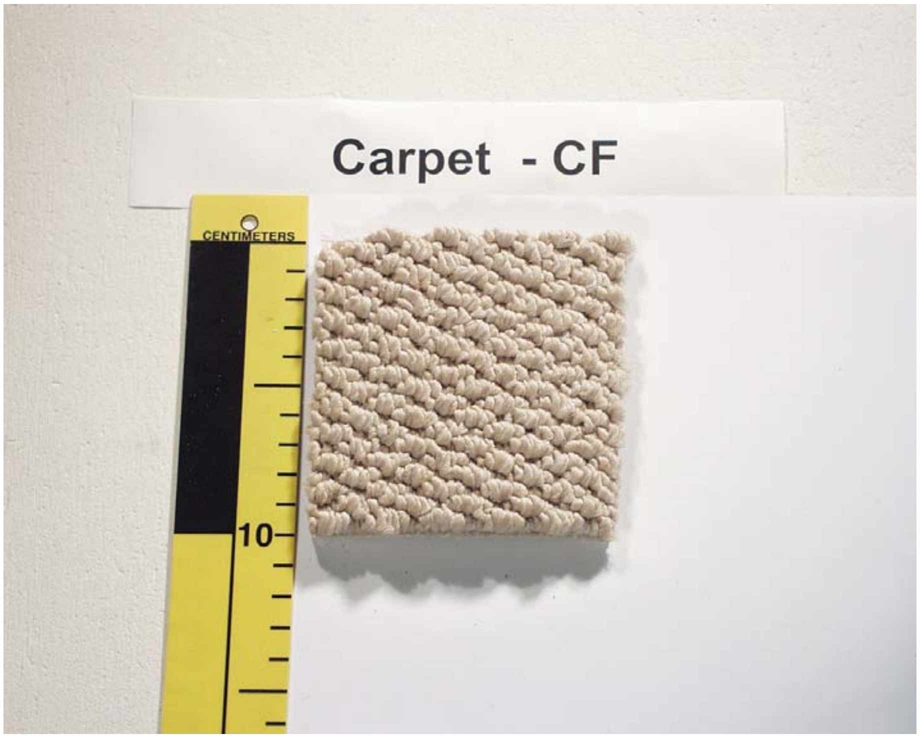

Figure D-21. Photograph of Carpet Sample Showing Olefin Pile.

two weeks. Then each sample was wrapped in an aluminum foil, except for the exposed side, and positioned in the cone calorimeter. In all tests, the olefin pile side was exposed to the thermal flux.

When exposed to 35 kW/m^2 of external heat flux (Figure D-22), the peak heat release rates for the three carpet samples ranged from 474 kW/m^2 to 718 kW/m^2. The carpet required about 54 seconds, on average, to achieve sustained ignition, and approximately 190 seconds to reach its peak heat release rate (Figure D-22). Three additional test samples were exposed to thermal flux at 70 kW/m^2 (Figure D-23) when exposed to the higher external heat flux, the carpeting reached its peak heat release rate in about half the time. Peak heat release rates for all three-carpet samples ranged from 1290 kW/m^2 to 1450 kW/m^2, with an average of 1370 kW/m^2.

For the lower flux exposure, the heat release curve exhibited a relatively brief step at around 200 kW/m^2 and then increased gradually to a single broad peak. As the carpet initially began to burn, some of the energy released was conducted into the olefin pile, but instead of producing a char, the polymer melted and formed a more uniform density fuel. As the burning continued, it increased at a relatively steady rate, reached its peak and decreased at a more rapid rate. At the higher flux exposure, the additional energy from the internal heating caused the melting to occur more rapidly, so the initial step seen at the lower flux was not observed.

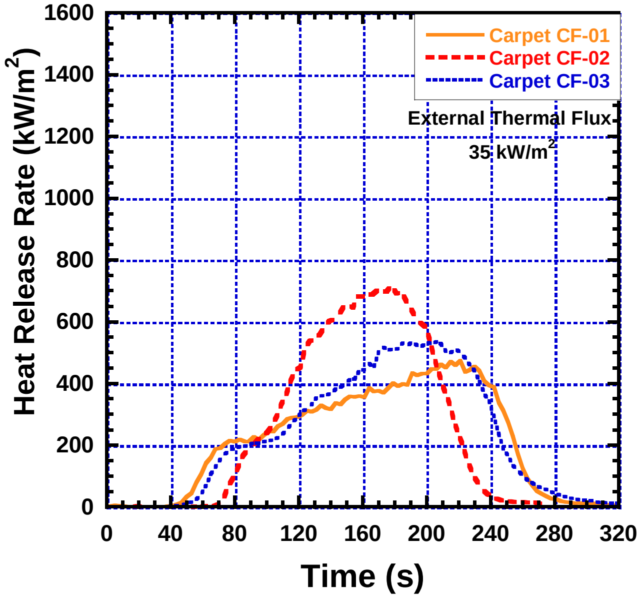

Figure D-22. Heat Release Rate versus Time for Carpet Sample Exposed to 35 kW/m^2 of External Heat Flux (CF). Samples are CF-01, CF-02, and CF-03.

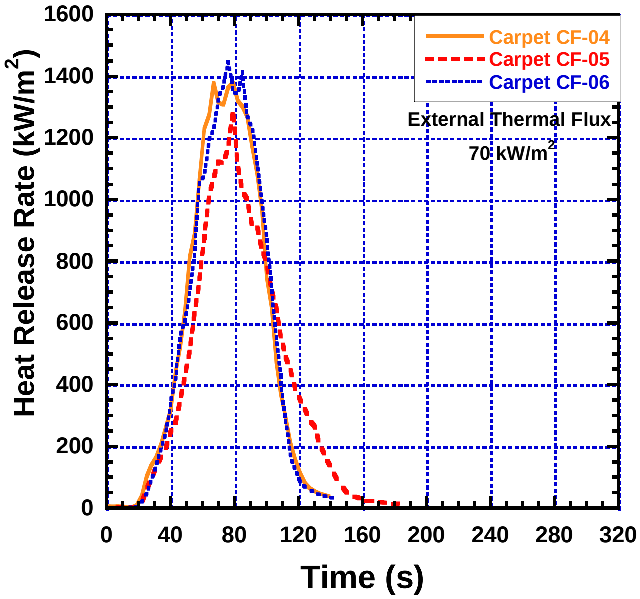

Figure D-23. Heat Release Rate versus Time for Carpet Sample Exposed to 70 kW/m^2 of External Heat Flux (CF). Samples are CF-04, CF-05, and CF-06.

D.2.8 Summary Tables

The materials that were tested and the sample identifiers that were used throughout the cone calorimeter test series are listed in Table D-6. The data that wer collected is summarized in Tables D-7 through D-19. The data tables provide the time to sustained ignition, peak heart release rate, time to peak heat release rate, total heat release, 60 s average heat release rate, total mass loss, average mass loss rate, average effective heat of combustion, average smoke yield, average carbon dioxide yield, average carbon monoxide yield, time to ignition, time to flameout, and a number of specimen properties. Each table groups a specific material that was exposed to a specific external heat flux.

Table D-6. Material Identification for Cone Calorimeter Experiments

Sample ID	Material	Fire Retardant/Non-Retardant	Description
PUF-FR	Polyurethane Foam (Ester)	Fire Retardant	Convoluted / Egg Crate Gray Color
PUF-NFR-A	Polyurethane Foam (Ether)	Non-Fire Retardant	Convoluted / Egg Crate Gray Color- Lot A
PUF-NFR-B	Polyurethane Foam (Ether)	Non-Fire Retardant	Convoluted / Egg Crate Gray Color- Lot B
CT-FR	Ceiling Tile	Fire Retardant	942 B (Commercial Equivalent 755) Textured
WP	Wood Paneling	Non-Fire Retardant	5 mm thick Plywood Substrate Antique Birch Finish
CF	Carpet	Non-Fire Retardant	100% Filament Olefin Color: Pottery (Beige)

Table D-7. Cone Calorimeter Data for Polyurethane Foam at 35 kW/m^2 (PUF-NFR-A).

Polyurethane Foam	**PUF-NFR-A-01**	**PUF-NFR-A-2**	**PUF-NFR-A-3**	**Average**
External Heat Flux 35 kW/m^2				
Test Results:				
Time to Sustained Ignition (s):	9.00	7	6	**7.3**
Peak Heat Release Rate (kW/m^2):	620	676	520	**605**
Time to Peak Heat Release Rate (s):	32.0	30	28	**30.0**
Total Heat Release (MJ/m^2):	15.6	16.3	15.4	**15.8**
60 s Average Heat Release Rate (kW/m^2):	262	268	248	**259**
Total Mass Loss (g):	6.25	6.2	5.94	**6.13**
Average Mass Loss Rate (g/s):	0.174	0.148	0.117	**0.146**
Average Effective Heat of Combustion (MJ/kg):	24.9	26.4	25.9	**25.7**
Average Smoke Extinction Area (m^2/kg):	206	285	235	**242**
Average CO_2 yield (g/g):	1.56	1.88	2.03	**1.8**
Average CO yield (g/g):	0.0136	0.0112	0.0129	**0.0126**
Specimen:				
Initial mass (g):	9.3	9.2	9.8	**9.4**
Thickness (mm):	25	25	25	**25.0**
Surface area (cm^2):	100	100	100	**100.0**
Test start time (s):	123	89	79	**97.0**
Time to ignition (s):	9	7	6	**7.3**
Time to flameout (s):	46	48	55	**49.7**

Table D-8. Cone Calorimeter Data for Fire Retardant Polyurethane Foam at 20 kW/m^2 (PUF-NFR-B).

Polyurethane Foam	**PUF-NFR-B-13**	**PUF-NFR-B-14**	**PUF-NFR-B-15**	**Average**
External Heat Flux 20 kW/m^2				
Test Results:				
Time to Sustained Ignition (s):	8	12	22	**14.0**
Peak Heat Release Rate (kW/m^2):	457	437	456	**450**
Time to Peak Heat Release Rate (s):	41	44	50	**45.0**
Total Heat Release (MJ/m^2):	9.87	10.33	10.0	**10.1**
60 s Average Heat Release Rate (kW/m^2):	206	205	192	**201**
Total Mass Loss (g):	4.55	4.48	4.05	**4.4**
Average Mass Loss Rate (g/s):	0.114	0.118	0.11	**0.114**
Average Effective Heat of Combustion (MJ/kg):	21.7	23.0	24.8	**23.2**
Average Smoke Extinction Area (m^2/kg):	323	343	385	**350**
Average CO_2 yield (g/g):	0	0	0	**0**
Average CO yield (g/g):	0.0103	0.012	0.0135	**0.0119**
Specimen:				
Initial mass (g):	6.7	6.7	6.7	**6.7**
Thickness (mm):	25	25	25	**25.0**
Surface area (cm^2):	100	100	100	**100**
Test start time (s):	82	92	83	**85.7**
Time to ignition (s):	8	12	22	**14.0**

Table D-9a. Cone Calorimeter Data for Polyurethane Foam at 35 kW/m^2 (PUF-NFR-B). Data and Averages are continued in Table D-9b.

Polyurethane Foam	**PUF-NFR-B-01**	**PUF-NFR-B-02**	**PUF-NFR-B-03**	**PUF-NFR-B-04**
External Heat Flux 36 kW/m^2				
Test Results:				
Time to Sustained Ignition (s):	4	5	9	5
Peak Heat Release Rate (kW/m^2):	519	532	541	577
Time to Peak Heat Release Rate (s):	26	26	33	32
Total Heat Release (MJ/m^2):	11.0	11.2	11.9	10.7
60 s Average Heat Release Rate (kW/m^2):	213	228	203	213
Total Mass Loss (g):	4.47	4.43	4.31	4.27
Average Mass Loss Rate (g/s):	0.135	0.148	0.13	0.142
Average Effective Heat of Combustion (MJ/kg):	24.7	25.4	27.5	25.0
Average Smoke Extinction Area (m^2/kg):	354	345	331	379
Average CO_2 yield (g/g):	0.86	0.87	1.3	0.91
Average CO yield (g/g):	0.0064	0.0071	0.0094	0.0111
Specimen:				
Initial mass (g):	9.1	9.3	9.5	9.2
Thickness (mm):	30	30	30	25
Surface area (cm^2):	100	100	100	100
Test start time (s):	87	75	74	84
Time to ignition (s):	4	5	9	5
Time to flameout (s):	37	37	44	36

Table D-9b. Cone Calorimeter Data for Polyurethane Foam at 35 kW/m^2 (PUF-NFR-B). Data and Averages are continued from Table D-9a.

Polyurethane Foam	**PUF-NFR-B-05**	**PUF-NFR-B-06**	**Average (for PUF-NFR-B -01 through -06)**
External Heat Flux 36 kW/m^2			
Test Results:			
Time to Sustained Ignition (s):	5	5	**5.5**
Peak Heat Release Rate (kW/m^2):	637	644	**575**
Time to Peak Heat Release Rate (s):	29	32	**29.7**
Total Heat Release (MJ/m^2):	11.0	10.2	**11.0**
60 s Average Heat Release Rate (kW/m^2):	211	211	**213**
Total Mass Loss (g):	4.43	4.51	**4.4**
Average Mass Loss Rate (g/s):	0.148	0.15	**0.142**
Average Effective Heat of Combustion (MJ/kg):	24.8	22.7	**25.0**
Average Smoke Extinction Area (m^2/kg):	489	326	**371**
Average CO_2 yield (g/g):	0.89	0.69	**0.92**
Average CO yield (g/g):	0.0103	0.0073	**0.0086**
Specimen:			
Initial mass (g):	9	9.2	**9.2**
Thickness (mm):	25	25	**27.5**
Surface area (cm^2):	100	100	**100**
Test start time (s):	81	78	**79.8**
Time to ignition (s):	5	5	**5.5**
Time to flameout (s):	35	36	**37.5**

Table D-10. Cone Calorimeter Data for Fire Retardant Polyurethane Foam at 40 kW/m^2 (PUF-NFR-B).

Polyurethane Foam	**PUF-NFR-B-16**	**PUF-NFR-B-17**	**PUF-NFR-B-18**	**Average**
External Heat Flux 40 kW/m^2				
Test Results:				
Time to Sustained Ignition (s):	4	3	4	**3.7**
Peak Heat Release Rate (kW/m^2):	706	878	877	**820**
Time to Peak Heat Release Rate (s):	28	30	29	**29**
Total Heat Release (MJ/m^2):	10.6	8.87	9.78	**9.8**
60 s Average Heat Release Rate (kW/m^2):	219	239	242	**233**
Total Mass Loss (g):	4.67	4.64	4.48	**4.6**
Average Mass Loss Rate (g/s):	0.156	0.172	0.166	**0.165**
Average Effective Heat of Combustion (MJ/kg):	22.8	19.1	21.8	**21.2**
Average Smoke Extinction Area (m^2/kg):	264	372	320	**319**
Average CO_2 yield (g/g):	0.04	0	0	**0.01**
Average CO yield (g/g):	0.0108	0.007	0.0081	**0.0086**
Specimen:				
Initial mass (g):	0.7	6.8	6.7	**4.7**
Thickness (mm):	25	25	25	**25**
Surface area (cm^2):	100	100	100	**100**
Test start time (s):	81	84	81	**82**
Time to ignition (s):	4	3	4	**3.7**

Table D-11. Cone Calorimeter Data for Fire Retardant Polyurethane Foam at 60 kW/m^2 (PUF-NFR-B).

Polyurethane Foam	**PUF-NFR-B-19**	**PUF-NFR-B-20**	**PUF-NFR-B-21**	**Average**
External Heat Flux 60 kW/m^2				
Test Results:				
Time to Sustained Ignition (s):	4	3	3	**3.3**
Peak Heat Release Rate (kW/m^2):	993	1170	1299	**1154**
Time to Peak Heat Release Rate (s):	24	24	23	**24**
Total Heat Release (MJ/m^2):	11.5	14.5	7.49	**11.2**
60 s Average Heat Release Rate (kW/m^2):	252	268	264	**261**
Total Mass Loss (g):	4.54	4.43	4.28	**4.4**
Average Mass Loss Rate (g/s):	0.189	0.153	0.225	**0.189**
Average Effective Heat of Combustion (MJ/kg):	25.2	32.8	17.5	**25.2**
Average Smoke Extinction Area (m^2/kg):	330	342	319	**330**
Average CO_2 yield (g/g):	0	0.74	0	**0.25**
Average CO yield (g/g):	0.0118	0.0302	0.0043	**0.0154**
Specimen:				
Initial mass (g):	6.8	6.8	6.7	**6.8**
Thickness (mm):	25	25	25	**25**
Surface area (cm^2):	100	100	100	**100**
Test start time (s):	85	84	96	**88**
Time to ignition (s):	4	3	3	**3.3**

Table D-12a. Cone Calorimeter Data for Polyurethane Foam at 70 kW/m^2 (PUF-NFR-B). Data and Averages are continued in Table D-12b.

Polyurethane Foam	**PUF-NFR-B-07**	**PUF-NFR-B-08**	**PUF-NFR-B-09**
External Heat Flux 71 kW/m^2			
Test Results:			
Time to Sustained Ignition (s):	4	3	3
Peak Heat Release Rate (kW/m^2):	806	820	881
Time to Peak Heat Release Rate (s):	18	20	21
Total Heat Release (MJ/m^2):	11.8	11.1	13.0
60 s Average Heat Release Rate (kW/m^2):	248	257	0.84
Total Mass Loss (g):	3.8	4.39	4.35
Average Mass Loss Rate (g/s):	0.181	0.209	0.181
Average Effective Heat of Combustion (MJ/kg):	31.0	25.3	29.8
Average Smoke Extinction Area (m^2/kg):	429	318	395
Average CO_2 yield (g/g):	0.64	0.35	0.67
Average CO yield (g/g):	0.0085	0.003	0.0073
Specimen:			
Initial mass (g):	9.2	9.1	9.1
Thickness (mm):	30	30	30
Surface area (cm^2):	100	100	100
Test start time (s):	104	78	77
Time to ignition (s):	4	3	3
Time to flameout (s):	25	25	27

Table D-12b. Cone Calorimeter Data for Polyurethane Foam at 70 kW/m^2 (PUF-NFR-B). Data and Averages are continued in Table D-12a.

Polyurethane Foam	**PUF-NFR-B-10**	**PUF-NFR-B-11**	**Average (PUF-NFR-B -01 to -11)**
External Heat Flux 71 kW/m^2			
Test Results:			
Time to Sustained Ignition (s):	3	3	**3.2**
Peak Heat Release Rate (kW/m^2):	1083	1094	**937**
Time to Peak Heat Release Rate (s):	22	20	**20.2**
Total Heat Release (MJ/m^2):	12.6	11.8	**12.0**
60 s Average Heat Release Rate (kW/m^2):	264	243	**203**
Total Mass Loss (g):	4.66	4.49	**4.3**
Average Mass Loss Rate (g/s):	0.194	0.214	**0.196**
Average Effective Heat of Combustion (MJ/kg):	27.1	26.2	**27.9**
Average Smoke Extinction Area (m^2/kg):	410	366	**384**
Average CO_2 yield (g/g):	0.44	0.35	**0.49**
Average CO yield (g/g):	0.0076	0.0062	**0.0065**
Specimen:			
Initial mass (g):	9.1	9	**9.1**
Thickness (mm):	25	25	**28.0**
Surface area (cm^2):	100	100	**100**
Test start time (s):	91	87	**87.4**
Time to ignition (s):	3	3	**3.2**
Time to flameout (s):	26	23	**25.2**

Table D-13. Cone Calorimeter Data for Fire Retardant Polyurethane Foam at 35 kW/m^2 (PUF-FR).

Polyurethane Foam	**PUF-FR-01**	**PUF-FR-02**	**PUF-FR-03**	**Average**
External Heat Flux 35 kW/m^2				
Test Results:				
Time to Sustained Ignition (s):	11.00	11	16	**12.7**
Peak Heat Release Rate (kW/m^2):	452	432	476	**453**
Time to Peak Heat Release Rate (s):	35.0	35	37	**35.7**
Total Heat Release (MJ/m^2):	8.69	8.5	8.58	**8.6**
60 s Average Heat Release Rate (kW/m^2):	155	150	151	**152**
Total Mass Loss (g):	5.95	5.86	5.67	**5.83**
Average Mass Loss Rate (g/s):	0.198	0.178	0.189	**0.188**
Average Effective Heat of Combustion (MJ/kg):	14.6	14.5	15.13	**14.7**
Average Smoke Extinction Area (m^2/kg):	539	474	542	**518**
Average CO_2 yield (g/g):	0.61	0.65	0.66	**0.6**
Average CO yield (g/g):	0.0618	0.0625	0.0623	**0.0622**
Specimen:				
Initial mass (g):	8.9	8.7	8.7	**8.8**
Thickness (mm):	25	25	25	**25.0**
Surface area (cm^2):	100	100	100	**100**
Test start time (s):	78	75	76	**76.3**
Time to ignition (s):	11	11	16	**12.7**
Time to flameout (s):	42	46	46	**44.7**

Table D-14. Cone Calorimeter Data for Wood Paneling at 35 kW/m^2 (WP).

Wood Paneling	**WP-01**	**WP-02**	**WP-03**	**Average**
External Heat Flux 35 kW/m^2				
Test Results:				
Time to Sustained Ignition (s):	43.0	43	37	**41.0**
Peak Heat Release Rate (kW/m^2):	460	439	413	**437**
Time to Peak Heat Release Rate (s):	126	129	131	**129**
Total Heat Release (MJ/m^2):	31.2	30.8	30.9	**31.0**
60 s Average Heat Release Rate (kW/m^2):	207	0.52	206	**138.1**
Total Mass Loss (g):	20.7	21.2	21.6	**21.1**
Average Mass Loss Rate (g/s):	0.187	0.191	0.189	**0.189**
Average Effective Heat of Combustion (MJ/kg):	15.0	14.6	14.3	**14.7**
Average Smoke Extinction Area (m^2/kg):	94.1	11.27	111.68	**72.4**
Average CO_2 yield (g/g):	1.48	1.41	1.36	**1.42**
Average CO yield (g/g):	0.0054	0.0047	0.0043	**0.0048**
Specimen:				
Initial mass (g):	28.8	28.8	29.3	**29.0**
Thickness (mm):	6	6	6	**6.0**
Surface area (cm^2):	100	100	100	**100**
Test start time (s):	80	77	84	**80.3**
Time to ignition (s):	43	43	37	**41.0**
Time to flameout (s):	154	155	151	**153**

Table D-15. Cone Calorimeter Data for Wood Paneling at 70 kW/m^2 (WP).

Wood Paneling	**WP-04**	**WP-05**	**WP-06**	**Average**
External Heat Flux 70 kW/m^2				
Test Results:				
Time to Sustained Ignition (s):	14.00	16	14	**14.7**
Peak Heat Release Rate (kW/m^2):	531	542	509	**528**
Time to Peak Heat Release Rate (s):	84.0	84	85	**84.3**
Total Heat Release (MJ/m^2):	35.4	33.1	34.8	**34.4**
60 s Average Heat Release Rate (kW/m^2):	348	368	353	**356**
Total Mass Loss (g):	23.2	21.7	22.8	**22.6**
Average Mass Loss Rate (g/s):	0.249	0.259	0.254	**0.254**
Average Effective Heat of Combustion (MJ/kg):	15.3	15.2	15.2	**15.2**
Average Smoke Extinction Area (m^2/kg):	92.8	93.0	95.1	**93.6**
Average CO_2 yield (g/g):	1.47	1.43	1.43	**1.44**
Average CO yield (g/g):	0.0056	0.0055	0.0055	**0.0055**
Specimen:				
Initial mass (g):	30	28.6	29.5	**29.4**
Thickness (mm):	6	6	6	**6.0**
Surface area (cm^2):	100	100	100	**100**
Test start time (s):	86	83	79	**82.7**
Time to ignition (s):	14	16	14	**14.7**
Time to flameout (s):	105	99	104	**103**

Table D-16. Cone Calorimeter Data for Ceiling Tile at 35 kW/m^2 (CT).

Ceiling Tile	**CT-01**	**CF-02**	**CT-03**	**Average**
External Heat Flux 35 kW/m^2				
Test Results:				
Time to Sustained Ignition (s):	Did not ignite	Did not ignite	Did not ignite	
Peak Heat Release Rate (kW/m^2):	Did not ignite	Did not ignite	Did not ignite	
Time to Peak Heat Release Rate (s):	Did not ignite	Did not ignite	Did not ignite	
Total Heat Release (MJ/m^2):	Did not ignite	Did not ignite	Did not ignite	
60 s Average Heat Release Rate (kW/m^2):	Did not ignite	Did not ignite	Did not ignite	
Total Mass Loss (g):	Did not ignite	Did not ignite	Did not ignite	
Average Mass Loss Rate (g/s):	Did not ignite	Did not ignite	Did not ignite	
Average Effective Heat of Combustion (MJ/kg):	Did not ignite	Did not ignite	Did not ignite	
Average Smoke Extinction Area (m^2/kg):	Did not ignite	Did not ignite	Did not ignite	
Average CO_2 yield (g/g):	Did not ignite	Did not ignite	Did not ignite	
Average CO yield (g/g):	Did not ignite	Did not ignite	Did not ignite	
Specimen:				
Initial mass (g):	33.8	33.5	33.5	**33.6**
Thickness (mm):	15	15	15	**15.0**
Surface area (cm^2):	100	100	100	**100.0**
Test start time (s):	*83*	84	112	**93.0**
Time to ignition (s):	Did not ignite	Did not ignite	Did not ignite	
Time to flameout (s):	Did not ignite	Did not ignite	Did not ignite	

Table D-17. Cone Calorimeter Data for Ceiling Tile at 70 kW/m^2 (CT).

Ceiling Tile External Heat Flux 70 kW/m^2	**CT-04**	**CT-05**	**CT-06**	**Average**
Test Results:				
Time to Sustained Ignition (s):	9.00	7	8	**8.0**
Peak Heat Release Rate (kW/m^2):	55.4	56.4	61.0	**57.6**
Time to Peak Heat Release Rate (s):	21.0	19	20	**20.0**
Total Heat Release (MJ/m^2):	7.52	7.15	7.79	**7.5**
60 s Average Heat Release Rate (kW/m^2):	44.3	44.5	45.2	**44.7**
Total Mass Loss (g):	6.54	6.68	6.76	**6.66**
Average Mass Loss Rate (g/s):	0.031	0.036	0.033	**0.033**
Average Effective Heat of Combustion (MJ/kg):	11.5	10.7	11.5	**11.2**
Average Smoke Extinction Area (m^2/kg):	1.64	0	23.3	**8.3**
Average CO_2 yield (g/g):	0.00	0	0.0339	**0.0113**
Average CO yield (g/g):	0.0411	0.0252	0	**0.0221**
Specimen:				
Initial mass (g):	33.8	34.2	34.1	**34.0**
Thickness (mm):	15	15	15	**15.0**
Surface area (cm^2):	100	100	100	**100**
Test start time (s):	95	91	105	**97.0**
Time to ignition (s):	9	7	8	**8.0**
Time to flameout (s):	221	194	213	**209**

Table D-18. Cone Calorimeter Data for Carpet Flooring at 35 kW/m^2 (CF).

Carpet Flooring	**CF-01**	**CF-02**	**CF-03**	**Average**
External Heat Flux 35 kW/m^2				
Test Results:				
Time to Sustained Ignition (s):	38	68	40	**48.7**
Peak Heat Release Rate (kW/m^2):	474	718	536	**576**
Time to Peak Heat Release Rate (s):	221	178	206	**202**
Total Heat Release (MJ/m^2):	67.6	71.4	71.8	**70.3**
60 s Average Heat Release Rate (kW/m^2):	139	246	111	**166**
Total Mass Loss (g):	12.2	16.6	18.0	**15.6**
Average Mass Loss Rate (g/s):	0.052	0.102	0.068	**0.074**
Average Effective Heat of Combustion (MJ/kg):	55.3	43.1	40.0	**46.1**
Average Smoke Extinction Area (m^2/kg):	1118	792	816	**908**
Average CO_2 yield (g/g):	3.87	3.07	2.86	**3.27**
Average CO yield (g/g):	0.0584	0.0437	0.0424	**0.0482**
Specimen:				
Initial mass (g):	28.7	29.2	30.2	**29.4**
Thickness (mm):	11	11	11	**11.0**
Surface area (cm^2):	100	100	100	**100**
Test start time (s):	111	79	84	**91.3**
Time to ignition (s):	38	68	40	**48.7**
Time to flameout (s):	272	229	302	**267**

Table D-19. Cone Calorimeter Data for Carpet Flooring at 70 kW/m^2 (CF).

Carpet Flooring External Heat Flux 70 kW/m^2	CF-04	CF-05	CF-06	**Average**
Test Results:				
Time to Sustained Ignition (s):	20.0	19	20	**19.7**
Peak Heat Release Rate (kW/m^2):	1378	1288	1447	**1371**
Time to Peak Heat Release Rate (s):	79.0	79	76	**78.0**
Total Heat Release (MJ/m^2):	74.6	70.0	73.4	**72.6**
60 s Average Heat Release Rate (kW/m^2):	706	548	677	**644**
Total Mass Loss (g):	17.0	16.6	20.8	**18.2**
Average Mass Loss Rate (g/s):	0.172	0.132	0.224	**0.176**
Average Effective Heat of Combustion (MJ/kg):	43.84	41.94	35.28	**40.4**
Average Smoke Extinction Area (m^2/kg):	842.12	987.34	768.5	**866.0**
Average CO_2 yield (g/g):	3.36	3.13	2.6	**3.03**
Average CO yield (g/g):	0.0581	0.0531	0.0457	**0.0523**
Specimen:				
Initial mass (g):	28.9	29.7	29.4	**29.3**
Thickness (mm):	11	11	11	**11.0**
Surface area (cm^2):	100	100	100	**100**
Test start time (s):	91	91	85	**89.0**
Time to ignition (s):	20	19	20	**19.7**
Time to flameout (s):	120	147	112	**126**

D.3 IGNITION TEMPERATURE TESTS

Ignition temperatures for polyurethane plastics were required for simulation of the mockup experiments and then for the simulation of the full nightclub. ASTM D 1929 [3] provides a laboratory determination of the spontaneous ignition temperature (SIT) and flash ignition temperature (FIT) for plastics. Southwest Research Institute (SwRI) was contracted to conduct analyses on PUF-NFR-B samples to determine ignition temperatures. This is the same polyurethane foam that was installed in the full-scale mockup. The results of the SIT tests were used in the computer fire model simulation of the mockup tests.

The report from SwRI included in this appendix describes the test protocol as well as the test results for the foam samples.

(Note that the SwRI report refers to a PU<u>R</u> foam, not a PU<u>F</u> foam; this is a typographical error. Also note that NIST provided the density of 0.39 kg/m^3 to SwRI. This value, which was determined from the cone calorimeter experiments conducted at NIST, mistakenly included the mass of the aluminum pan. The correct value for density should have be reported as 0.22 kg/m^3. This error had no impact on the results of the SwRI ignition temperature tests.)

SOUTHWEST RESEARCH INSTITUTE®

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DEPARTMENT OF FIRE TECHNOLOGY
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FAX (210) 522-3377

ASTM D 1929 – 96 (Reapproved 2001)

Standard Test Method for
Determining Ignition Temperature of Plastics

Material ID: ***PUR-NFR-B***

Final Report
SwRI® Project No.: 01.10934.01.602a
Consisting of 5 Pages

Test Date: October 14, 2004
Report Date: November 9, 2004

Prepared for:

National Institute of Standards and Technology
Building and Fire Research Laboratory
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Director
Department of Fire Technology

HOUSTON, TEXAS (713) 977-1377 • WASHINGTON, DC (301) 881-0226

Introduction

ASTM D 1929 covers a laboratory determination of the spontaneous ignition temperature (SIT) and flash ignition temperature (FIT) of plastics using a hot-air furnace. The hot-air ignition furnace consists primarily of an electrical heating unit and specimen holder. The furnace tube is a vertical tube with an inside diameter of 100 ± 5 mm and a length of 230 ± 20 mm, made of ceramic that will withstand at least 750°C. The inner ceramic tube, with an inside diameter of 75 ± 5 mm, a length of 230 ± 20 mm, and a thickness of approximately 3 mm, is placed inside the furnace tube and positioned 20 ± 2 mm above the furnace floor on spacer blocks. The pilot flame is located immediately above the opening. The test apparatus is shown in Fig. 1 below.

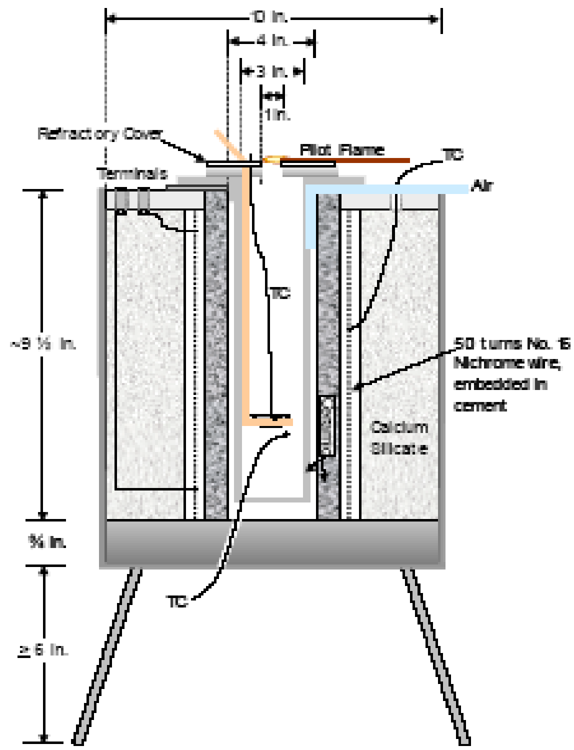

Figure 1. Schematic of SwRI's Hot-Air Furnace.

SIT is the minimum temperature at which the self-heating properties of the specimen lead to ignition or ignition occurs of itself, under specified test conditions, in the absence of any additional flame ignition source. The lowest air temperature at which the specimen burns during a 10-min period is recorded as the spontaneous ignition temperature.

FIT is the minimum temperature at which, under specified test conditions, sufficient flammable gases are emitted to ignite momentarily upon application of a small external pilot flame. The lowest air temperature at which a flash is observed during a 10-min period is recorded as the flash ignition temperature.

Sample Identification and Preparation

The National Institute of Standards and Testing (NIST), located in Gaithersburg, Maryland, provided a material identified as *PUR-NFR-B* for testing in accordance with ASTM D 1929. The material was described by the Client as "Polyurethane foam, convoluted, ether non-fire retardant" and was gray in color. Per NIST, the aerial density of the material was 0.39 kg/m^2. The material consisted of peaks and valleys with the peaks measuring 29 mm and the valleys measuring 10 mm. The material was received at SwRI on October 11, 2004. Upon receipt, samples were prepared for testing and conditioned in a controlled environment maintained at 23 ± 2°C (73 ± 5°F) and 50 ± 5% relative humidity for not less than 40 hours prior to testing. Tests were conducted October 14, 2004.

Sample preparation was in general accordance with ASTM D 1929. Because the density of the material was less than 100 kg/m^3, the test samples were prepared according to size instead of the normal 3-g weight. In accordance with ASTM D 1929, each test specimen was cut to 20 × 20 mm. Due to the uneven shape of the material (see Figure 1), the required height of 50 mm could not be achieved by stacking the samples and the 20 × 20-mm samples were left at the 10-29 mm height.

Results

Table 1 contains the results for the material provided by NIST. Test results are accurate to ± 5°C. A complete set of results and observations are presented at the end of this report. These test results relate only to the behavior of test specimens under the particular conditions of the test. They are not intended to be used, and shall not be used, to assess the potential fire hazards of a material in use.

Table 1. Ignition Temperature Data.

Material ID	SIT	FIT
PUR-NFR-B	410 °C	370 °C
	770 °F	698 °F

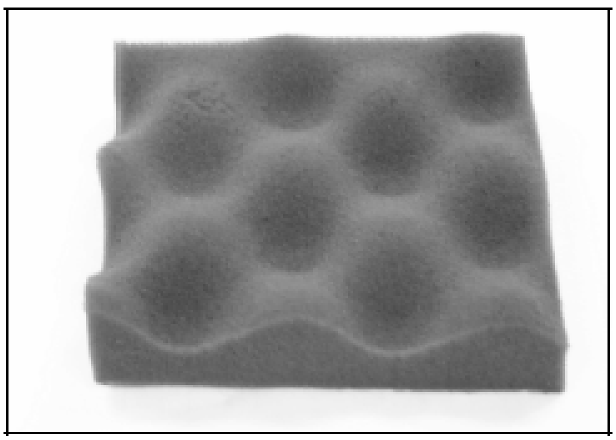

Figure 1. ***PUR-NFR-B.***

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ASTM D 1929 TEST DATA SHEET - SPONTANEOUS IGNITION

Client:	National Institute of Standards and Technology	*Ignition Type:*	Spontaneous
Operator:	J. Anderson	*Receipt Date:*	October 11, 2004
Test Date(s):	October 14, 2004	*Date Prepared by SwRI:*	October 14, 2004
Material ID:*	PUF-NFR-B	*Color:*	Gray
Description:*	Polyurethane foam, convoluted, ether, non fire-retardant	*Original Thickness:*	10 mm -29 mm
		Average Sample Mass:	0.35 g

SPONTANEOUS IGNITION TEMPERATURE (°C) : 410

** Information/instructions provided by the Client*

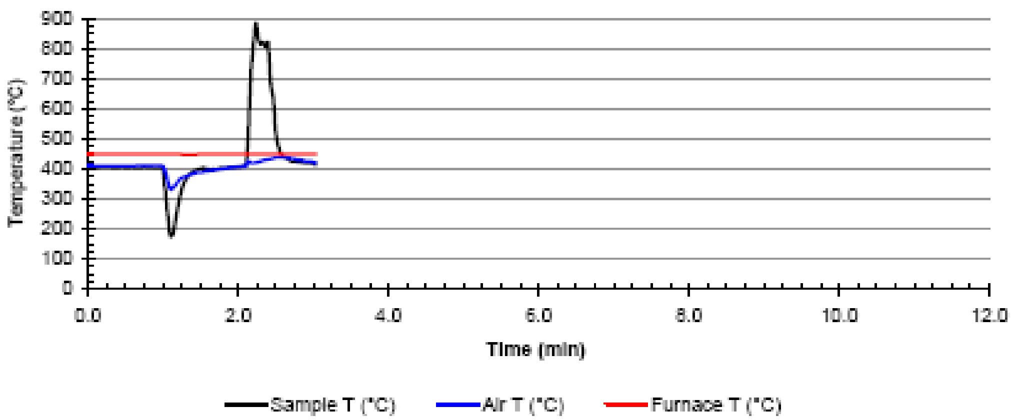
RESULTS

Test ID	Initial Mass (g)	Final Mass (g)	Mass Loss (g)	Initial Temperature (°C) Sample	Air	Furnace	Final Temperature (°C) Sample	Air	Furnace	Ignition
2884-2	0.34	0.07	0.27	347	350	392	345	350	391	No
2884-3	0.35	0.04	0.31	398	400	448	395	402	440	No
2884-4	0.35	0.03	0.32	450	450	494	778	465	494	Yes
2884-5	0.36	0.02	0.34	438	440	483	921	455	483	Yes
2884-6	0.34	0.02	0.32	427	430	469	848	448	470	Yes
2884-7	0.35	0.03	0.32	417	420	461	839	437	462	Yes
2884-8	0.34	0.02	0.32	405	410	450	817	423	449	Yes

SPONTANEOUS IGNITION OBSERVATIONS

	Insertion Time (min:sec)	Combustion Time (min:sec)	Observed Soot (min:sec)	Observed Smoke (min:sec)	Observed Foam	Observed Melt	Observed Bubbling	Total Test Time (min:sec)
2884-2	1:20	None	None	1:30	None	None	None	11:20
2884-3	1:10	None	None	1:16	None	None	None	11:10
2884-4	1:11	Flaming at 1:49	1:49	1:13	None	None	None	1:49
2884-5	1:14	Flaming at 2:00	2:01	1:16	None	None	None	2:01
2884-6	1:15	Flaming at 1:59	1:17	1:18	None	None	None	1:59
2884-7	1:10	Flaming at 1:45	1:12	1:14	None	None	None	1:45
2884-8	1:08	Flaming at 2:09	2:12	1:14	None	None	None	3:00

Test ID 2884-8



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ASTM D 1929 TEST DATA SHEET - FLASH IGNITION

Client:	National Institute of Standards and Technology	*Ignition Type:*	Flash
Operator:	J. Anderson	*Receipt Date:*	October 11, 2004
Test Date(s):	October 14, 2004	*Date Prepared by SwRI:*	October 14, 2004
Material ID:*	PUF-NFR-B	*Color:*	Gray
Description:*	Polyurethane foam, convoluted, ether, non fire-retardant	*Original Thickness:*	10 mm -29 mm
		Average Sample Mass:	0.35 g

** Information/Instructions provided by the Client*

FLASH IGNITION TEMPERATURE (°C) : 370

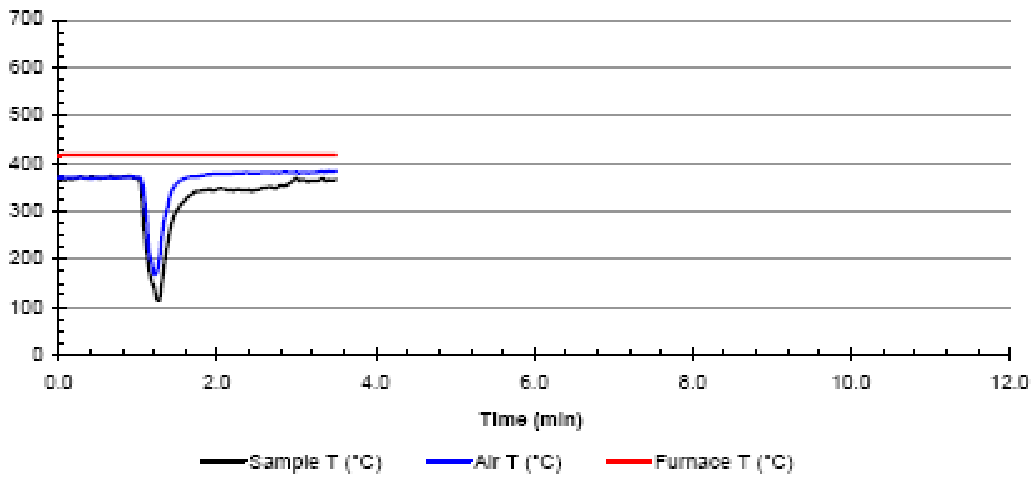
RESULTS

Test ID	Initial Mass (g)	Final Mass (g)	Mass Loss (g)	Initial Temperature (°C) Sample	Initial Temperature (°C) Air	Initial Temperature (°C) Furnace	Final Temperature (°C) Sample	Final Temperature (°C) Air	Final Temperature (°C) Furnace	Ignition
2884-9	0.35	0.06	0.29	349	350	390	356	353	392	No
2884-10	0.36	0.02	0.34	368	370	417	366	381	417	Yes
2884-11	0.34	0.03	0.31	356	360	398	360	362	399	No

FLASH IGNITION OBSERVATIONS

	Insertion Time (min:sec)	Combustion Type	Observed Soot (min:sec)	Observed Smoke (min:sec)	Observed Foam (min:sec)	Observed Melt (min:sec)	Observed Bubbling (min:sec)	Total Test Time (min:sec)
2884-9	1:12	None	None	None	None	None	None	11:12
2884-10	1:18	Flaming at 3:02	None	3:10	None	None	None	3:30
2884-11	1:16	None	None	None	None	None	None	11:16

Test ID 2884-10



2884-5	0.36	0.02	0.34	438	440	483	921	455	483	Yes
2884-6	0.34	0.02	0.32	427	430	469	848	448	470	Yes
2884-7	0.35	0.03	0.32	417	420	461	839	437	462	Yes
2884-8	0.34	0.02	0.32	405	410	450	817	423	449	Yes

SPONTANEOUS IGNITION OBSERVATIONS

	Insertion Time (min:sec)	Combustion Time (min:sec)	Observed Soot (min:sec)	Observed Smoke (min:sec)	Observed Foam	Observed Melt	Observed Bubbling	Total Test Time (min:sec)
2884-2	1:20	None	None	1:30	None	None	None	11:20
2884-3	1:10	None	None	1:16	None	None	None	11:10
2884-4	1:11	Flaming at 1:49	1:49	1:13	None	None	None	1:49
2884-5	1:14	Flaming at 2:00	2:01	1:16	None	None	None	2:01
2884-6	1:15	Flaming at 1:59	1:17	1:18	None	None	None	1:59
2884-7	1:10	Flaming at 1:45	1:12	1:14	None	None	None	1:45
2884-8	1:08	Flaming at 2:09	2:12	1:14	None	None	None	3:00

Test ID 2884-8